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Wood Extraction with Farm Tractor and Sulky: Estimating Productivity, Cost and Energy Consumption

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Abstract A winch and a sulky can transform a farm tractor into an effective small-scale logging machine, closely resembling a wheeled cable skidder. The additional cost of these implements is very small, but they offer significant benefits when extracting timber under the conditions of small-scale forestry. The authors developed a productivity model for skidding timber with wheeled farm tractors, equipped with winch and sulky. The origin data pool contained over 300 individual skidding cycles, extracted from 8 separate tests. Statistical analysis of the data allowed calculating a simple mathematical relationship for estimating skidding productivity as a function of significant work conditions, such as: piece size, winching distance, tractor power, skidding distance and crew size. This model can provide useful directions to prospective users, contributing to operation planning, costing and optimization. It can predict a large proportion of the variability in the data and was successfully validated using reserved cycle records, extracted from the same data pool and not used for model development. Depending on tractor power and piece size, the average turn volume and productivity can exceed respectively 2 m^3 per cycle and 4 m^3 per Scheduled Machine Hour (SMH). Top performance can reach 8 m^3 SMH^{-1}, with heavy tractors and large logs.

Keywords Farm-forestry · Skidding · Productivity · Energy consumption · Cost analysis

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Introduction

Modern forestry mechanization offers the benefits of multiplying operator productivity (Spinelli and Magagnotti 2010) and of drastically enhancing work safety (Bell 2002), but requires a significant capital investment, which often exceeds the capacity of non-industrial operators. That explains the enduring popularity of adapted farm tractors, which are used for a variety of forest harvesting tasks, including felling, processing, extraction and transport. In turn, part-time forestry work may offer good employment opportunity to local entrepreneurs, contributing to the reduction of seasonal idling. Temporary conversion to forestry work requires appropriate implements, such as winches, trailers and loaders. Log skidding is probably the simplest task, and that requiring the lowest investment in specialised implements. At its simplest, skidding can be obtained by pulling directly off the tractor drawbar, but this technique is inefficient and causes much soil disturbance (Conway 1976). More often, logs are pulled to the tractor with a winch, which is also used to lift the log ends off the ground during skidding. A better lift can be obtained by using a skidding arch, which can be bolted to tractor rear end (integral arch), or mounted on a semitrailer (trailing arch). The trailing arch can roll on tracks or wheels, which respectively define the logging arch and the sulky (Pearce and Stenzel 1972). Winch and sulky can transform a farm tractor into an effective logging machine, closely resembling a wheeled cable skidder (Ryans 1980). In particular, using a sulky results in less skidding resistance, higher skidding speed, larger turn size, cleaner logs, reduced soil disturbance and cable wear (Pearce and Stenzel 1972). What’s more, such adaptation incurs a very small additional cost, which can be estimated in the range of 4,000 € for the winch and 3,000 € for the sulky. Trailing arches have been around for a long time, and are the direct descendant of the big wheels, used when animal teams were the main source of power (Burroughs 1953). The concept was then adapted to tractor skidding, and trailing arches became extremely popular between the 1940s and the 1960s. They were produced in large numbers by industrial manufacturing companies such as Ajax, Atey, Carco, Garret, Hyster and Legras. In 1955 Gearmatic launched a new arch with built-in double drum winch, and in the same year Letourneau–Westinghouse coupled a winch-fitted wheeled sulky to the front train of an industrial tractor: the two elements were connected by an articulation and the sulky wheels were powered by electric motors. This machine was the ancestor of the modern cable skidder, which appeared in a more recognizable form few years later, and quickly supplanted the tractor and trailing arch. By the 1970s, trailing arches had virtually disappeared from industrial logging operations, with few local exceptions (Vaughan 1988). Today, their legacy is represented by the small sulkies used with All Terrain Vehicles (ATV; Hedderick 2008) or skidsteer loaders (Hallbrook and Lee 2002), and by the integral trailing winches offered by some manufacturers for coupling to farm tractors (Ryans 1980; Denninger 1982; Pritchard 1986). However, ATVs are too small for effective commercial use, whereas integral trailing winches are often too expensive for part-time use. On the contrary, a standard winch and a sulky can be fitted to any tractor at a very limited cost, and can be used for part-time forest operations. This simple technology has a

significant potential for effective deployment in farm forestry (Kittredge et al. 1996) and in developing countries (Ladrach 2004), which explains the interest for a general function that can predict the productivity and the cost of skidding with farm tractor and sulky, under different work conditions. No such function is yet available, because the trailing arch disappeared from commercial operations long ago, and the few modern studies are either episodic (Hill 1991) or did not aim at producing significant statistical functions to be used for prediction purposes (Spinelli and Baldini 1992). The goal of this paper is therefore to produce a general statistical function for predicting machine productivity and estimating skidding cost.

Materials and Methods

The study was conducted in Central Italy, in an area where skidding with farm tractors and sulkies is still a very popular wood extraction technique. The authors conducted eight tests at seven different sites, described in Table 1. Data was collected during actual commercial operations, on six different tractors. All machines were four wheel-drive farm tractors, with a nominal power ranging from 48 to 116 kW. All tractors carried at least a basic forestry guarding, including ROPS or reinforced cab, nose guard and belly pan. All tractors were fitted with mechanical single-drum winches, bolted to the rear end and drawing power from the power take-off (PTO) shaft. Winch traction force was always in the range of 60 kN. Counterweights were mounted onto the tractor nose or on the front wheels. All sulkies were manufactured by local workshops, using recycled truck wheels, airplane tires and robust steel pipe. They were very similar in structure and size, regardless of tractor size. They consisted of a square vertical frame with a roller fairlead at the centre of the horizontal top beam. This frame stood on a semitrailer, mounted on two wheels and carrying a short tong with a swivel hook eye, for connecting to the tractor hitch. Diagonal braces tied the vertical frame with the semitrailer. All sulkies were 2.2 m wide and 2 m high. Operators adopted two main extraction techniques, using the sulky to haul suspended or semi-suspended loads. The former technique was used with short logs, measuring up to five meters. In this case, one end of the logs was supported by a chain placed between the two arch props, while the other end was lifted using the winch cable. This technique could not be applied to full stems, which were skidded with the butt ends lifted and the top ends dragging on the ground.

All machines were operated by experienced professionals, who had run them for at least 5 years. Skidding crews consisted of one or two workers, depending on the operator. No attempt was made to normalize individual performances by means of productivity ratings (Scott 1973), recognizing that all kinds of normalization or corrections can introduce new sources of errors and uncontrolled variation in the data material (Gullberg 1995). On the other hand, the skills of study operators were considered representative of the region and the task, and the relatively large sample allowed levelling out the variation caused by the human factor (Nurminen et al. 2006).

Table 1 Description of the test sites

Site		A	B	C	D	E	F	G
Test		1	2	3	4	5	6	7–8
Municipality		Vetralla	Castel del Piano	S.Fiora	Valentano	Onano	Capranica	S. Martino
Province		Viterbo	Grosseto	Grosseto	Viterbo	Viterbo	Viterbo	Viterbo
Altitude	m a.s.l.	470	1,205	1,195	547	586	385	605
Slope gradient	%	12	21	29	14	23	46	23
Trail gradient	%	5	14	14	6	8	10	13
Road density	m ha^{-1}	6	7	25	50	40	21	18
Tree Species		*Quercus cerris L.*	*Fagus sylvatica L.*	*Abies Alba L.*	*Quercus cerris L.*	*Quercus cerris L.*	*Castanea sativa L.*	*Castanea sativa L.*
Management		High forest	High forest	High forest	Coppice	Coppice	Coppice	Coppice
Treatment		Selection cut	Selection cut	Thinning	Clearcut	Clearcut	Clearcut	Clearcut
Age	Years	80–130	88	55	14	15	18	17
Removal	m^3 ha^{-1}	46.4	78	119	121.1	91.7	92.3	172.8
Removal	Trees ha^{-1}	10	112	278	1,671	1,987	1,300	1,350
Residual density	Trees ha^{-1}	612	324	788	140	120	40	36
Tree DBH	m	0.598	0.303	0.225	0.109	0.092	0.115	0.146
Stem Height	m	22.5	18.7	18.3	8.7	7.3	8.7	9.5
Stem volume	m^3	4.465	0.524	0.428	0.072	0.046	0.071	0.128
Harvesting System		SWS	SWS	FLS	FLS	SWS	FLS	FLS

The values in the table represent mean values for each given site; *SWS* Short wood system, i.e. extraction of logs; *FLS* Full length system, i.e. extraction of delimbed stems; on sites D and E, tractors with sulky were used to extract the standards only, numbering 71 and 87 units ha^{-1}, respectively. The average age of the standards was 4–5 times the coppice rotation and their stem volume was 1.076 and 0.531 m^3, respectively for site D and E

Table 2 Description of the work steps

Work step	Description
Move in	The tractor drives without a load from the roadside landing to the loading site on the cutover. This step begins when the tractor leaves the landing, and ends when the tractor reaches the loading site
Load	All work at the loading site, functional to assembling and hitching a full load. That includes: manoeuvring, hooking, winching, fastening the load
Move out	The tractor drives with a load from the loading site to the roadside landing. This step begins when the tractor leaves the loading site, and ends when the tractor reaches the landing
Unload	All work at the landing site, functional to releasing the load near the right stack. That includes: manoeuvring, unhooking, reeling in the winch cable, stacking
Delay	All delays, due to mechanical, personal and organizational causes. Delays caused by the study itself were excluded from the records

A time-motion study was carried out to evaluate machine productivity and to identify those variables that are most likely to affect it (Bergstrand 1991). Each skidding cycle was stop watched individually, separating productive time from delay time (Björheden et al. 1995). A description of the work steps is reported in Table 2. Extraction distances were determined with a measuring tape. No correction was made for slope gradient, so that these distances represent the actual paths covered by the tractors. Load size was estimated differently for logs and full-length delimbed stems. The volume of all logs in each load was determined by measuring their length and their diameter at mid-length. The volume of stem wood loads was estimated by measuring the diameter at breast height (DBH) of all stems in each turn and then converting DBH into stem wood volume using single-entry tariff tables, specifically calculated for the purpose on the basis of 100 sample trees per site, distributed along all diameter classes. Sample trees were scaled by measuring DBH, total length and diameter at mid-length.

Regression analysis of the time-study data was used to develop a model capable of predicting productivity as a function of statistically significant independent variables (SAS Institute Inc 1999). Documented validation is a prerequisite of production models derived from time study data (Howard 1992), and it was conducted according to the same procedure used by Adebayo et al. (2007) for a similar modeling study. The dataset was partitioned at random into two subsets: the first subset, containing 70% of the observation number was used to calculate the model through regression analysis; the second subset, with the remaining 30% of the observations (reserved data), was used for validation. To this purpose, the model was used to predict the reserved data, then the predicted figures were correlated with the observed figures, and the resulting r^2 (validated r^2) was used as a measure for the predictive capacity of the equations. Furthermore, a paired *t* test was used to test the differences between predicted and observed figures.

Tractor rates were calculated with the method described by Miyata (1980), on an estimated annual utilization of 1,000 scheduled machine hours (SMH) and a depreciation period of 10 years. Scheduled machine time represented the time the machine spent on the worksite, and included both productive work time and delays.

The costs of fuel, insurance, repair and service were obtained directly from the operators. Labor cost was set to 15 € SMH^{-1} inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 20% to account for overhead costs (Hartsough 2003). It must be stressed that all operators were industrial contractors, with no access to the subsidized "red-diesel" available to farmers. Hence, they used industrial diesel fuel, paid its full market price. Access to "red-diesel" would have allowed a reduction of the hourly rates between 4 and 5%. In fact, these tractors used little fuel, and their daily consumption varied between 22 and 52 l. Therefore, the hourly rate was not very sensitive to changes in diesel prices.

Both direct and indirect fossil energy consumption were estimated, reflecting the same principles followed by Pellizzi (1992) in his energy analysis of Italian agriculture. The direct energy consumed by the farm tractor was estimated by multiplying the measured diesel consumption by an energy content of 37 Mega Joule per litre (MJ l^{-1}; Bailey et al. 2003). This value was inflated by 1.2 in order to account for the additional fossil energy consumed in the production and transportation of diesel fuel (Pellizzi 1992). The indirect consumption represented by tractor manufacturing, repair and maintenance was estimated as 30% of the total energy consumption of the tractor (Mikkola and Ahokas 2010). Further detail on financial and energy cost calculation is shown in Table 3.

Table 3 Costing: assumptions, cost items and total cost

Test		5	6	8	2, 3, 7	1	4
Tractor power	kW	48	55	63	72	96	116
Investment	Euro	41,000	44,500	47,000	52,000	83,000	93,000
Resale value	Euro	8,200	13,350	14,100	15,600	24,900	27,900
Service life	Years	10	10	10	10	10	10
Utilization	h year^{-1}	1,000	1,000	1,000	1,000	1,000	1,000
Interest rate	%	4	4	4	4	4	4
Depreciation	Euro year^{-1}	3,280	3,115	3,290	3,640	5,810	6,510
Interests	Euro year^{-1}	1,050	1,219	1,288	1,425	2,274	2,548
Insurance	Euro year^{-1}	1,050	1,219	1,288	1,425	2,274	2,548
Diesel	Euro h^{-1}	3.0	3.3	3.9	4.4	5.5	7.2
Lubricant	Euro h^{-1}	1.1	1.2	1.4	1.6	2.0	2.6
R & M	Euro h^{-1}	2.6	2.5	2.6	2.9	4.6	5.2
Labour	Euro h^{-1}	30.0	30.0	30.0	15.0	30.0	30.0
subtotal	Euro h^{-1}	42.1	42.6	43.8	30.4	52.5	56.6
Overheads	Euro h^{-1}	8.4	8.5	8.8	6.1	10.5	11.3
Total rate	Euro h^{-1}	50.5	51.1	52.5	36.5	63.0	67.9
Direct energy	MJ h^{-1}	120	133	155	178	222	289
Indirect energy	MJ h^{-1}	53	59	68	78	98	127
Total energy	MJ h^{-1}	173	192	224	256	320	416

Cost in Euro (€) as on May 25, 2010. 1 € = 1.22 US$

The study material consisted in 324 tractor turns, necessary for extracting 579 m^3. Overall, the time study sessions lasted 155 SMH, equal to 19 full work days.

Results and Discussion

Table 4 shows the overall test results. Productivity was always above 3 m^3 SMH^{-1}, except for test six, which was constrained by a very small piece size and a relatively long winching distance. The average load size was always larger than 1 m^3, often reaching or exceeding the 2 m^3 limit. Maximum load size was in the range of 2 m^3, and almost reached 5 m^3 with the largest 116 kW tractor. These results are probably most remarkable for those operations characterized by a small piece size, since accumulating such large loads with small stems implies assembling a bunch of 20 or more stems, and it is unlikely that a standard winch assembly could hold so many pieces. Our results compare favorably with those reported in other studies about farm tractor extraction under similar work conditions (Prebble 1986; Turner et al. 1988; Zečić et al. 2005). On the other hand, the productivity of cable skidders in comparable hardwood (Erickson et al. 1991; Mirkala and Rostam 2009) or mountain softwood stands (Sabo and Poršinsky 2005) is clearly superior, and in the range of 10–12 m^3 SMH^{-1}. However, modified farm tractors fetch lower hourly rates than specialized skidders, which explains a relatively moderate extraction cost. This can drop below 10 € m^{-3}, and is not much higher than the 7–8 € m^{-3} recorded by the

Table 4 Extraction productivity and cost: summary table

Test		1	2	3	4	5	6	7	8
Site		A	B	C	D	E	F	G	G
Tractor	kW	96	72	72	116	48	55	72	63
Crew	n°	2	1	1	2	2	2	1	2
Skidding distance	m	1,119	216	73	362	95	470	420	493
Winching distance	m	7	10	12	7	20	17	9	12
Piece size	m^3	0.634	0.403	0.539	1.026	0.411	0.072	0.134	0.129
Load size	m^3	2.473	1.147	1.337	3.040	1.053	1.604	1.860	2.164
Max load size	m^3	3.168	1.940	1.967	4.753	1.895	2.052	2.548	3.318
Turn time	min	31.8	20.1	18.0	24.2	23.6	65.3	37.2	34.1
Delay factor		0.178	0.412	0.605	0.234	0.265	0.381	0.323	0.182
Suspension		Full	Full	Half	Half	Half	Half	Half	Half
Speed empty	km h^{-1}	8.1	4.3	3.3	5.5	3.0	5.5	5.2	4.7
Speed loaded	km h^{-1}	7.3	3.5	2.5	4.4	2.1	4.8	4.4	4.6
Productivity	m^3 SMH^{-1}	**4.7**	**3.7**	**4.7**	**7.9**	**3.2**	**1.5**	**3.0**	**4.3**
Cost	Euro m^{-3}	**13.3**	**9.9**	**7.7**	**8.6**	**15.7**	**33.6**	**12.0**	**12.3**
Fossil energy	MJ m^{-3}	67	69	54	53	54	126	84	53

SMH Scheduled machine time, i.e. worksite time including all delays, *Delay Factor* delay time/net work time

same authors for wood extraction with dedicated forestry units in Italy (Spinelli and Magagnotti 2010). These costs are much lower than the 40–60 € m^{-3} reported for cable yarding under similar stands in Southern Italy (Zimbalatti and Proto 2009). Nevertheless, this is not a comparative study, and one should not use it to make any direct technology comparisons.

Figure 1 reports element time consumption in graphic form. Again, test six emerges as the one with the highest time consumption per turn. Delay time is also longer in test six, and is generally related to the hanging-up of the loads during winching, which was particularly frequent, due to the long winching distance and the very rough terrain. In all cases, actual skidding represented a minor part of the total turn time. That may explain the very low recorded fuel consumption: the tractor engine seldom worked under a full load, and generally ran at a very low speed during such work steps as loading and unloading, and during delay time.

Table 5 reports the time consumption regressions calculated for each of the main work stages. They may help understanding process dynamics, as well as the potential impact of such independent variables as: extraction and winching distance, piece volume, engine power and crew size. The same table also shows the consolidated productivity model, which can be used for predicting output as a function of the same variables. This regression is highly significant and explains almost 70% of the overall variability, despite the confounding effect of delay time, which is typically erratic (Spinelli and Visser 2009). Better results could be obtained by excluding delay time from the observations, or by spreading it evenly (Spinelli et al. 2009). However, the authors thought that the inclusion of the original delay time records could better represent the inherent variability of the process, and would not invalidate the equation, which does retain a high statistical significance. In fact, model validation returned encouraging results, with a validated r^2 higher than the original coefficient of determination, and a clear absence of any statistically significant differences between actual and predicted productivity figures.

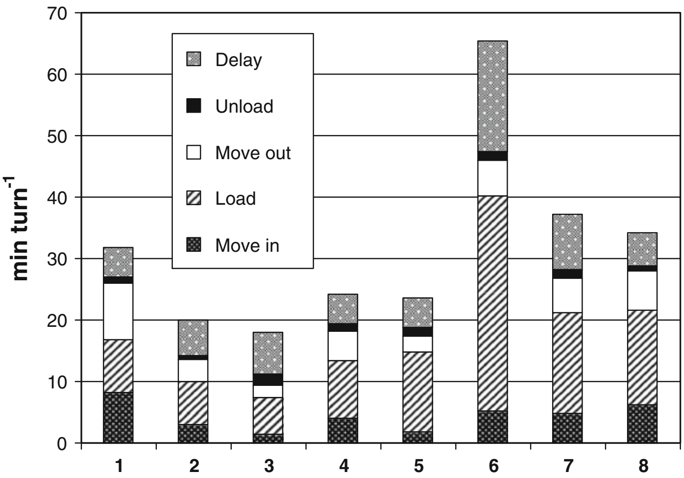

Fig. 1 Average turn time recorded in the 8 tests and subdivided by functional activity

Table 5 Regressions for estimating time consumption, and productivity model

		r^2	f	*P*
Individual work steps				
Move in	min $turn^{-1} = -3.058 + 0.434\ Dist^{0.32} - 0.021$ kW	0.890	1,294.9	<0.0001
Load	min $turn^{-1} = 1.561 + 0.386$ Winch + 0.848 Pieces	0.719	410.6	<0.0001
Move out	min $turn^{-1} = -1.918 + 0.939\ Dist^{0.38} - 0.018$ kW − 0.001 Dist * Suspension	0.919	1,203.4	<0.0001
Unload	min $turn^{-1}$ = 1.29 if half suspended, 0.86 if fully suspended	Unpaired *t* test		<0.0001
Delay factor	0.43 if one operator, 0.23 if two operators	Unpaired *t* test		<0.0001
Productivity model				
$m^3\ SMH^{-1} = 1.662 - 0.022\ Dist^{0.70} - 0.084$ Winch + 2.699 Piece size + 0.040 kW + 1.136 Chokerman		0.677	92.5	<0.0001
Validation regression: $r^2 = 0.728$, f = 253.7; *P* = < 0.0001				
Paired *t* test Actual vs. Predicted: Diff = 0.047; *P* = 0.678				

Dist Skidding distance in m, *kW* tractor power in kW, *Winch* winching distance in m, *Pieces* Number of pieces in the load, *Suspension* indicator variable, 1 if the load is fully suspended, 0 if half suspended; *SMH* scheduled machine hours, *Piece* size average size of the pieces in the load, in m^3, *Chokerman* indicator variable, 0 if the driver works alone, 1 if the driver works with the assistance of a choker man (two-men crew), *Delay Factor* delay time/net work time

As an example, the model was used to draw the graphs in Fig. 2, which represent productivity as a function of extraction distance and piece size, for a 70 kW tractor manned by a two-man crew and a winching distance of 15 m.

The model indicates that the most important factor affecting skidding productivity is piece size, and that extraction distance comes only after other more important elements, such as winching distance. However, it should be noted that like many other forest operation studies, this study was conducted under the

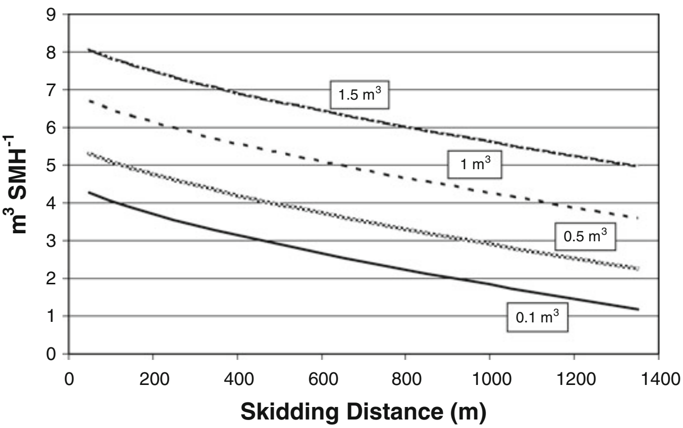

Fig. 2 Extraction productivity as a function of skidding distance and piece size. *Note:* the *curves* in the graph were calculated for a 70 kW tractor, a two-men crew and a 15 m winching distance

conditions of actual commercial operations, and not under a strictly controlled laboratory environment. Therefore, the study design is not balanced and the regression should not be used to determine the exact weight of each independent variable, but only to establish its general significance. In contrast, the regression model proved a good predictor of extraction productivity for practical purposes, as demonstred by its successful validation.

From this model, one may safely infer that hiring a second operator does not offer any significant cost advantage, at least for the Italian labor rates. Such result is particularly interesting if one considers that all winches in the study were operated from the tractor seat, so that the unassisted driver would need to walk back to the tractor after hooking each winch load, before he could start winching. If the use of an assistant did not allow for a dramatic productivity increase under such conditions, then it is almost certain that adopting a new radio-controlled winch will guarantee the superior profitability of the one-man crew. In this respect, it is interesting to notice that with the exception of the crew on test 4, all the other two-men crew were composed by relatives. These may have additional reasons for working together, other than pure financial calculation.

Using the sulky to achieve full suspension did not seem to offer any productivity advantage. The overall productivity model did not react to the "full suspension" indicator variable, whose statistical significance was very low. This variable had a significant effect on the regressions predicting the time of a loaded trip and the loaded trip speed (not reported in the table, because redundant), but the effect was very small. On the other hand, one should realize that full suspension is only possible with relatively short logs, and requires crosscutting the original stems. In turn, this will determine a reduction of piece size, which is bound to decrease productivity. Hence, full suspension cannot achieve any productivity advantage, and it should only be applied when maneuverability is a crucial pre-requisite. Clearly, the maneuverability of a fully suspended short load is far superior than that of a half suspended long load. Among other things, a fully suspended load can be backed up, which is impossible with a half suspended long load. This may turn particularly useful when landing space is limited, or when operating in selection cuts with a dense residual stand. Contrary to dragging, full suspension prevents any contamination with soil.

Compared to a standard forestry winch connected to the three-point hitch, the main disadvantages of the sulky are its additional length and the lack of any anchoring devices. The former reduces the maneuverability of the machine, and makes it less suitable to thinning operations, which generally offer reduced turning spaces; the latter imposes resorting to relatively large tractors, in order to avoid sliding back when winching. Both limits can be overcome rather easily, respectively by lifting the empty sulky with the aid of the winch (Vaughan 1988) and by adding some simple anchoring devices to the sulky frame (TDB 2002).

It must be noted that until now, all sulkies used in traditional forest operations are produced by small local workshops. While that could represent an additional technical advantage for rural communities, it also means that the sulkies in current use do not comply with the safety regulations prescribed in the European Union. In fact, no specimen actually bears the compulsory CE compliance marking. The

process leading to CE marking is relatively simple and incurs a moderate expense. However, such expense is generally higher than the cost of one sulky, and it can be offset only if the shop is planning to produce several units within a reasonable time interval. So far, no shop has made plans towards CE marking, and no machine is suitable for marketing in the European Union. That is a main non-technical obstacle to the further introduction of sulkies to European forestry.

Skidding with farm tractor and sulky incurs a fossil energy use of 50–100 MJ m^{-3}. These are the equivalent of the direct energy contained in 1.3 and 2.7 l of diesel, respectively. This result is somewhat higher than that reported by Picchio et al. (2009) for tractor skidding under similar conditions (about 36 MJ m^{-3}) but in the same order of magnitude. In fact, energy consumption was calculated with different methods in the two studies, and that may account for the marginal difference.

Conclusions

Winch and sulky can transform a farm tractor into an effective skidding machine, especially suited to small-scale forestry. This machine can drag loads between 1 and 5 m^3, depending on tractor power and piece size.

The model derived from this study offers a reliable tool to estimate machine productivity and extraction cost, under a variety of work conditions typical of farm forestry. This information can be used for operation costing, planning and optimization. The model can also be used to determine if the additional cost of a winching assistant is offset by the productivity increase thus gained.

Unfortunately, recent scientific literature does not seem to offer any general prediction models for the productivity of either specialized skidders or adapted farm tractors, and therefore one cannot determine with any accuracy the eventual productivity gains specifically obtained with the sulky. In the future, it could be useful to develop such models, or to perform comparative studies on the specific subject.

While describing the benefits of using a sulky, this study also highlights the need for improving its design and construction. Expanding the use of sulkies requires that an industrial manufacturing company initiates serial production. Registered engineers could redesign the product and enhance it in a number of different ways—for instance by fitting it with some anchoring device. Serial production could guarantee a minimum recognized quality standard, and it could result in a further reduction of purchase price. What is more, it would allow certifying the compliance of the product with machine safety standards, which is essential to its marketing.

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